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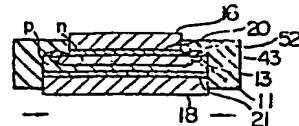
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⑯ An electrode for a semiconductor device and method of making such an electrode.

⑰ A supporting electrode (16,18) is mounted on at least one surface of a semiconductor substrate (11). The sides of the substrate (11) and the electrode are covered by epoxy resin (43). In order to avoid problems arising from the different thermal expansion coefficients of the various materials, the electrode is formed of a copper-carbon fiber composition metal in which carbon fibers are embedded in a spiral and lie parallel to the major surface of the substrate, so that the electrode exhibits anisotropic thermal expansion properties. Its coefficient of expansion parallel to the major surface of the substrate is lower than its coefficient in the direction perpendicular to this surface, since the expansion coefficient of the substrate (e.g. silicon) is lower than that of the resin (43).

FIG. 3



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*TITLE MODIFIED  
see front page*

"Semiconductor Device"

This invention relates to a semiconductor device comprising a semiconductor substrate at least one electrode bonded to a major surface of said substrate and a body of synthetic resin material covering at least one side surface of said substrate and at least one side surface of said electrode. The invention also relates to a method of making such a device and to a method of making an electrode for such a device.

In semiconductor devices, a semiconductor element is placed in a metal-ceramic composite casing or is covered by an insulating material such as synthetic resin or glass for protection from the adverse effects of the external atmosphere and external forces and for keeping a long distance along the surface and hence a high dielectric strength. Covering with synthetic resin is relatively simple and thus suitable for inexpensive semiconductor devices. A typical example of an inexpensive semiconductor device is one produced by soldering an L-shaped lead wire onto both sides of a small semiconductor element and covering the semiconductor element and the lead wires with synthetic resin (for instance, the MR 2500 series medium current silicon rectifiers (50 to 1000 volts, 25 amperes, diffused junction) available from MOTOROLA Inc.).

*BAD ORIGINAL*

However, resin-mold packaged semiconductor devices of large current capacity, for example, about 400A at 1000V have not yet been produced. One reason for this is that the semiconductor substrate, electrode materials and synthetic resin used in such a device have 5 different thermal expansion characteristics.

An object of this invention is to provide a semiconductor device, particularly one of large current capacity, in which the semiconductor element is protected at its sides by resinmolding, and in which problems caused by differences of thermal expansion 10 are avoided.

The invention as claimed seeks to provide a remedy. The aim is that the thermal expansion coefficient of the electrode body or electrode member in the direction parallel to the surface to which the semiconductor element is attached is equal to that of the 15 semiconductor element, and that the thermal expansion coefficient of the electrode in the direction perpendicular to this surface is approximately the same as that of the synthetic resin. Perfect matching of the coefficients of thermal expansion in this manner is generally not practicable, but the invention proposes that the matching 20 of the coefficients is better than if the electrode does not have anisotropic expansion characteristics.

To produce a semiconductor device of the invention with such the desired thermal expansion characteristics, there is preferably employed a copper-carbon composite metal (or a composite body having 25 carbon fibers embedded in substantially uniform distribution in a matrix of copper) having different thermal expansion coefficients in

directions perpendicular to each other. In this way, good matching of the thermal expansion coefficients of the semiconductor substrate, the electrode materials and the synthetic resin may be achieved.

Embodiments of this invention will now be described by way of example with reference to the accompanying drawings, in which:-

Fig. 1 is an explanatory exploded cross-sectional view of a semiconductor device embodying the invention;

Fig. 2 is a perspective view of the supporting electrode in Fig. 1;

Fig. 3 is a cross-sectional view of the resin-molded semiconductor device of Fig. 1 in the assembled state;

Fig. 4 is a sectional view of another device embodying the invention which is a button-type diode; and

Fig. 5 is a sectional view of yet another device embodying the invention, which is a composite device.

Fig. 1 is an exploded view showing the parts of the device before assembly of the semiconductor substrate and the supporting electrodes. A silicon substrate 11 has in its periphery a moat 12, the inner wall of which includes the end of the rectifying junction. A passivation glass material 13 is placed and sintered in the moat 12 and there are evaporated three-layer films 14 and 15 for ohmic contact each of which consists, for example, of a 0.1  $\mu\text{m}$  thick chromium (Cr) layer, a 0.6  $\mu\text{m}$  thick nickel (Ni) layer and a 1.5  $\mu\text{m}$  thick silver (Ag) layer. In addition, there are top and bottom supporting electrodes 16 and 18. Each of supporting electrodes 16, 18 is plated on at least one of its surfaces with silver to form a

silver film 17,19 of 10  $\mu\text{m}$  thickness. Each of the electrodes 16,18 itself is made of a material having the property of thermal expansion anisotropy as will be described below. For the purpose of this invention, the thermal expansion coefficient of the top and bottom 5 electrodes 16 and 18 in the direction of arrow B, i.e. in any direction along the surface of the silicon substrate 11 (see Fig. 2) is preferably within the range  $3.5 \times 10^{-6}/^\circ\text{C}$  to  $5 \times 10^{-6}/^\circ\text{C}$ , and the thermal expansion coefficient thereof in the direction of arrow A (see Fig. 2) is preferably in the range  $15 \times 10^{-6}/^\circ\text{C}$  to  $30 \times 10^{-6}/^\circ\text{C}$ .

10 A copper carbon fiber composite metal as shown in Fig. 2 is suitable for the electrodes 16,18 having this anisotropy. In this composite metal, carbon fibers each several microns in diameter are arranged in concentric circles or in a spiral having its centre at the core of the structure, the space between the fibers being filled 15 with copper material. The volume ratio (by volume percent) of copper to carbon fibers is preferably kept in the range of 35 to 55% (carbon fibers): 65 to 45% (copper).

16 The thermal expansion coefficient  $K_d$  of the supporting electrodes 18 and 19 in the direction of arrow B is given by the following 20 expression, within the elastic limit:

$$K_d = \frac{K_f \cdot E_f \cdot V_f + K_m \cdot E_m (1 - V_f)}{E_f \cdot V_f + E_m (1 - V_f)}$$

where  $K_f$ : coefficient of thermal expansion of fiber,

$K_m$ : coefficient of thermal expansion of matrix,

$E_f$ : Young's modulus of fiber,

$E_m$ : Young's modulus of matrix,

$V_f$ : volume ratio of fiber content.

If  $K_f = 3 \times 10^{-6}/^{\circ}\text{C}$ ,  $K_m = 16.5 \times 10^{-6}/^{\circ}\text{C}$ ,  $E_f = 23000 \text{ kg/mm}^2$ ,

$E_m = 12000 \text{ kg/mm}^2$  and  $V_f = 0.4$ , then  $K_d \approx 5.5 \times 10^{-6}/^{\circ}\text{C}$ , which is approximately equal to the actual measured value.

The thermal expansion coefficient of the supporting electrodes

10 16 and 18 in the direction of arrow A is constant,  $18 \times 10^{-6}/^{\circ}\text{C}$

irrespective of the volume ratio of carbon fiber content.

To produce the supporting electrodes 16 and 18, a quantity of copper powder is first mixed into an aqueous solution of 3% methyl cellulose to form a slurry. Then, copper plated carbon fibres are

15 soaked into the copper powder in the slurry and subsequently the carbon fibers are arranged in a spiral form by a machine while a tension of 0.9 to 1.1 Kg is exerted on them to form a composite body. This composite body is then temporarily sintered at  $350^{\circ}\text{C}$  for one hour in a hydrogen ( $\text{H}_2$ ) atmosphere, and is thereafter

20 subjected to hot pressing in a pressed condition at  $250 \text{ Kg/cm}^2$  and at a temperature of  $980^{\circ}$  to  $1050^{\circ}\text{C}$  for one hour in the  $\text{H}_2$  atmosphere. The supporting electrode is then machined into the desired shape. The resulting electrode has a small thermal expansion coefficient in the directions parallel to its main surfaces (B 25 direction) because of the concentrically or spirally restrained carbon fibers which have a small thermal expansion coefficient, but has a

larger thermal expansion coefficient in its thickness direction (A direction) than that in the B direction because of there is slight restraint of the carbon fibers in this direction.

The supporting electrode thus produced is used to fabricate 5 the semiconductor device of Fig. 3 in the following steps:-

The electrodes 16 and 18 are each plated on one of their surfaces with silver to form the layers 17 and 19, and are then - subjected to stabilization by heat treatment at 250°C for 30 minutes in a vacuum. This stabilization step stabilizes the A- and B-direction 10 thermal expansion coefficient the electrodes 16 and 18. Subsequently, solder layers 20 and 21 are formed on the plated surfaces 17 and 19 of the supporting electrodes 16 and 18 by evaporating lead (Pb) and then tin (Sn) onto the surfaces 17 and 19. These solder layers 20 and 21 are Pb5Sn and are 50  $\mu\text{m}$  thick. The electrodes 16 and 18 15 with the solder layers 20 and 21 formed on them are then mounted on the silicon substrate 11 which has the ohmic contacts 14 and 15 on both surfaces. This mounting operation is performed at 295 to 305°C for 10 min., with a pressure of 0.2  $\text{kg}/\text{cm}^2$ .

A silicon rubber 52 shown in Fig. 3 is placed on the sintered 20 glass 13 in the moat 12 and is cured at 200°C for two hours. An epoxy resin 43 shown in Fig. 3 is applied and cured in the temperature range of 120°C to 150°C for 2 to 7 hours. The thermal expansion coefficient of this resin 43 is  $25 \times 10^{-6}/\text{°C}$ . The silicon rubber 52 serves as a buffer preventing the resin 43 from causing damage to 25 the glass 13 by direct contact with the glass. Even though the glass 13 is not sintered on the semiconductor, the silicon rubber 52, which

covers the surface of the semiconductor 11 except where the electrodes 16 and 18 are attached, serves as a cushion to relieve the tensile stress caused by the difference between the thermal expansion coefficients of the substrate material 11 and the epoxy resin 43.

5 In this device, since the thermal expansion coefficients of the substrate 11 and the electrodes 16 and 18 are approximately equal in their main surface directions (the B-direction), no damage is caused to the substrate 11 and glass 13 by the different thermal expansion coefficients of the semiconductor 11 and the electrodes 16 and 18,  
10 or by the thermal fatigue of the adhesive layers 20 and 21 between the semiconductor 11 and the electrodes 16 and 18. As for the thermal expansion coefficients of the electrodes 16 and 18 and the resin 43 in the B-direction, the sides of the electrodes 16 and 18 are always stretched in the radial direction by the synthetic resin 43, (i.e.  
15 there is a shrinkage-fit) which provides very good close adherence between the sides of the electrodes 16 and 18 and the synthetic resin 43.

As to the thermal expansion coefficients of the electrode members 16 and 18 and the synthetic resin 43 in the silicon-thickness direction  
20 (A-direction), since the thermal expansion coefficients of the two materials are approximately equal and there is little difference between the thermal expansions of the two materials, sliding between these two parts does not occur. Consequently there is satisfactory close adherence between the electrodes 16 and 18 and the protective resin 43 in cooperation with the steady adherence by the above-mentioned binding. Thus, moisture is prevented from permeating into

the semiconductor substrate 11 from outside through these boundaries between the electrodes 16 and 18 and resin 43.

Fig. 4 shows the invention applied to a so-called button-type diode. A silicon semiconductor element 22 is adhesively sandwiched by upper and lower electrodes 26 and 28 through solder layers 30 and 31, respectively. Silicon rubber 32 is attached to the end walls of the element 22, and epoxy resin 33 covers the element 22 over its sides between the upper and lower electrodes 26 and 28. In this embodiment, the thermal expansion coefficients of the electrodes 26 and 28 and the epoxy resin 33, and the anisotropic thermal expansion coefficients of the electrodes 26 and 28 in the A- and B-directions are all the same as in the device of Figs. 1 to 3. In addition, good close adhesion is between the electrodes 26 and 28 and the protective synthetic resin 33 is similarly achieved, thus preventing moisture from penetrating from outside into the element 22 through the boundaries between these parts.

While the two-terminal semiconductor devices are illustrated above, this invention is not limited to such devices, but can be naturally used for three-terminal devices such as thyristors or the like, without any limitation.

It will be understood from the foregoing description that this invention can be applied to a particularly large-sized semiconductor which is covered with synthetic resin, because of the good functional matching among the thermal expansion coefficients of the semiconductor, electrodes and synthetic resin.

The thermal expansion coefficients of the electrodes used in

the invention can be selected to be appropriate values within a certain range with respect to the surface direction and thickness direction thereof. This selection of thermal expansion coefficients may be performed by changing the proportions of the copper and carbon 5 fibers in the electrodes, the shape and size of the fibers and the manner of mixing of the materials. It is preferable that the thermal expansion coefficient of the electrodes in the main surface direction is in the range  $3.5 \times 10^{-6}/^{\circ}\text{C}$  to  $5 \times 10^{-6}/^{\circ}\text{C}$ , to match that of silicon, which is  $3.5 \times 10^{-6}/^{\circ}\text{C}$ . Reduction of the thermal 10 expansion coefficient of the electrodes to less than that of silicon would require an increase of the ratio of carbon fibers to copper with a consequent decrease of the thermal conductivity of the electrodes which is impractical.

The thermal expansion coefficient of the composite material of 15 copper and fibers in its thickness direction is desirably selected so that the difference of thermal expansion between the electrodes and the resin material (which has a thermal expansion coefficient of  $25 \times 10^{-6}/^{\circ}\text{C}$ ) at the boundary between them is less than the width of a single carbon fiber the radius of which is usually about 5  $\mu\text{m}$ . 20 Hence it is desirable for the coefficient of thermal expansion of the electrodes in this direction to be within the range  $20 \times 10^{-6}/^{\circ}\text{C}$  to  $30 \times 10^{-6}/^{\circ}\text{C}$ .

In Fig. 5, elements corresponding to those of Fig. 1 are identified by the same reference numerals. This semiconductor device 25 differs from that of Fig. 3 in that a plurality of silicon semiconductor elements 11 are mounted on the lower supporting electrode 18

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instead of the single element 11 shown in Fig. 3. That is to say, the device of Fig. 5 is a composite device. The electrodes 18,16 are formed in the same manner as those of Fig. 3, though here of course there are two of each electrode 16 and 18.

5 As well as a plurality of silicon semiconductor elements 11 on the lower electrode 18, the device of the invention may incorporate circuit elements such as capacitors, and resistors.

CLAIMS:

1. A semiconductor device comprising a semiconductor substrate (11,22) at least one electrode (16,18,26,28) bonded to a major surface of said substrate (11,22) and a body of synthetic resin material (43,53) covering at least one side surface of said substrate (11,22) and at least one side surface of said electrode (16,18,26,28),  
5 characterised in that  
the coefficient of thermal expansion of said electrode (16,18,26,28) in directions parallel to said major surface of the substrate (11,22) to which the electrode is bonded is substantially less than the  
10 coefficient of thermal expansion of the electrode in the direction perpendicular to said major surface.
2. A device according to claim 1 wherein the said coefficient of thermal expansion in directions parallel to said major surface is in the range  $3.5 \times 10^{-6}/^{\circ}\text{C}$  to  $5 \times 10^{-6}/^{\circ}\text{C}$  and the said coefficient of thermal expansion in the direction perpendicular to said major  
15 surface is in the range  $15 \times 10^{-6}/^{\circ}\text{C}$  to  $30 \times 10^{-6}/^{\circ}\text{C}$ .
3. A device according to claim 1 or claim 2 wherein said electrode (16,18,26,28) is a composite body having fibers embedded in a metal matrix, the fibers being arranged substantially parallel to said major surface  
20 of the substrate (11,22) and having a coefficient of thermal expansion not greater than that of the substrate (11,22).
4. A device according to claim 3 wherein, at least at a surface region of said electrode (which surface region is bonded to the substrate) the fibers are arranged in an annular configuration comprised  
25 of a plurality of concentric annuluses or in a spiral configuration with

a plurality of spirals having a common centre.

5. A device according to claim 3 or claim 4 wherein the fibers are carbon fibers and the metal matrix is copper, the percentage by volume of carbon fibers being in the range 35 to 55% and the 5 percentage by volume of copper being in the range 45 to 65%.

6. A method of making an electrode (16,18,26,28) for use in a semiconductor device,

characterised by the steps of:

a) preparing a composite body comprising copper-plated carbon 10 fibers arranged in a predetermined form, and  
b) subjecting said composite body to heat treatment while under pressure so as to produce an electrode exhibiting anisotropic thermal expansion.

7. A method according to claim 6 wherein, in said predetermined 15 form, said fibers are arranged spirally or concentrically.

8. A method according to claim 6 or claim 7 wherein step (a) comprises

(i) mixing copper powder in an aqueous solution of 3% methyl 20 cellulose to form a slurry,  
(ii) soaking copper-plated carbon fibers in said slurry, and  
(iii) then arranging said fibers in a spiral form to provide said composite body.

9. An electrode produced by a method according to any one of claims 6, 7 and 8.

10. A method of making a semiconductor device according to  
claim 1 including the steps of

- (a) forming a metal film (17,19) on at least one surface of an  
electrode according to claim 9,
- 5 (b) then bonding said electrode by means of solder to the major  
surface of the semiconductor substrate (11,22) and
- (c) covering at least one side surface of said substrate and at  
least one side surface of said electrode with synthetic resin  
in a mold.

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FIG. 1

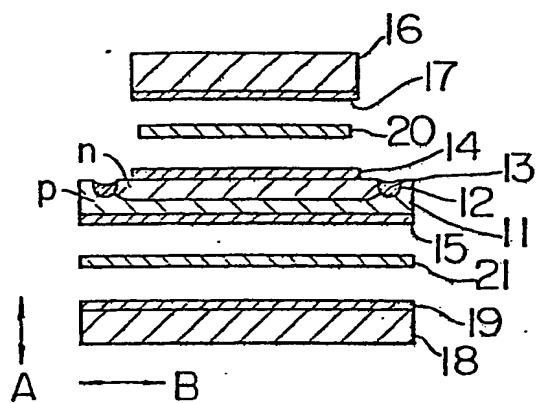


FIG. 2

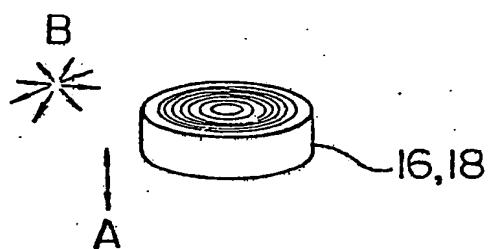


FIG. 3

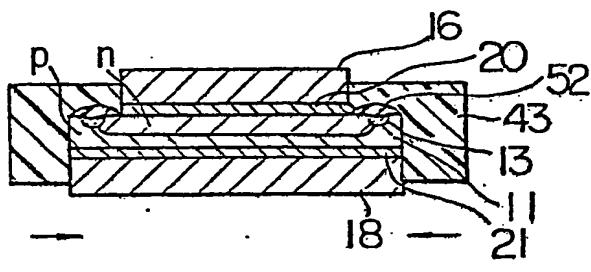


FIG. 4

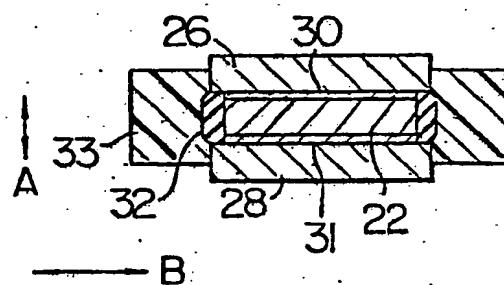
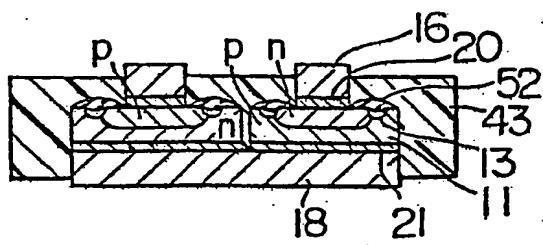


FIG. 5





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0012019  
Application number

LF 79 20 2719

DOCUMENTS CONSIDERED TO BE RELEVANT		CLASSIFICATION OF THE APPLICATION (Int. Cl. 5)	
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	<p><u>FR - A - 2 387 498</u> (HITACHI)</p> <p>* Figures 4,5; claim 1; page 6, line 14 - page 7, line 12; page 11, lines 19-22; page 12, lines 3-7 *</p> <p>&amp; DE - A - 2 816 249</p> <p>---</p> <p><u>US - A - 3 969 754</u> (HITACHI)</p> <p>* Claims 1,2,5,10; column 6, lines 60-68; column 3, lines 29-33 *</p> <p>---</p> <p><u>FR - A - 1 213 484</u> (COMP. FRANC. THOMSON-HOUSTON)</p> <p>* Abstract *</p> <p>---</p> <p><u>DE - A - 2 824 250</u> (HITACHI)</p> <p>* Figure 1; claims 1,3,4; page 7, 1st paragraph; page 17, paragraphs 3-4; page 18, paragraph 4 - page 19, paragraph 1 *</p> <p>&amp; NL - A - 78 05992</p> <p>-----</p>	<p>1,3-10</p> <p>1-3,5</p> <p>1</p> <p>1-10</p>	<p>H 01 L 23/48 H 01 L 21/48 H 01 L 23/04 H 01 L 25/04</p> <p>TECHNICAL FIELDS SEARCHED (Int.Cl. 5)</p> <p>H 01 L 23/48 H 01 L 23/04</p> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons</p> <p>&amp;: member of the same patent family, corresponding document</p>
	<p><input checked="" type="checkbox"/> The present search report has been drawn up for all claims</p>		
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